ABSTRACT

An operating method is provided for a motor vehicle diesel engine having an exhaust emission control system that includes a three-way catalytic converter and an SCR catalytic converter situated one behind the other in the flow direction of the exhaust gas. The diesel engine is operated, at least intermittently, with an air-fuel ratio of approximately \( \lambda = 1.0 \) in a first operating range in which the SCR catalytic converter falls below a predefined minimum temperature and with excess air that is typical for normal diesel engine operation in a second operating range in which the SCR catalytic converter exceeds the predefined minimum temperature. An output signal of an exhaust gas sensor situated downstream from the three-way catalytic converter and which is correlated with a NOx concentration of the exhaust gas is used to set the air-fuel ratio in the first operating range.
Figure 3
OPERATING METHOD FOR A MOTOR VEHICLE DIESEL ENGINE HAVING AN EXHAUST EMISSION CONTROL SYSTEM

BACKGROUND AND SUMMARY OF THE INVENTION

[0001] Exemplary embodiments of the present invention relate to an operating method for a motor vehicle diesel engine having an exhaust emission control system, comprising a three-way catalytic converter and an SCR catalytic converter situated one behind the other in the flow direction of the exhaust gas, in which the diesel engine is operated, at least intermittently, with an air-fuel ratio of approximately \( \lambda = 1.0 \) in a first operating range during which the SCR catalytic converter is below a predefined minimum temperature, and is operated with excess air that is typical for normal diesel engine operation in a second operating range during which the SCR catalytic converter exceeds the predefined minimum temperature.

[0002] German patent document DE 10 2009 015 900 A1 discloses a generic operating method but does not mention how the stoichiometric air-fuel ratio of approximately \( \lambda = 1.0 \), which is atypical for diesel engine operation, is set. This has proven to be difficult, in particular for an exhaust emission control system that is comparatively slightly heated, since lambda sensors which are often used for this purpose provide erroneous measured values.

[0003] Exemplary embodiments of the present invention, therefore, provide an operating method that allows an accurate, reliable setting of a stoichiometric air-fuel ratio of approximately \( \lambda = 1.0 \), in particular for an exhaust emission control system that is comparatively slightly heated.

[0004] In accordance with exemplary embodiments of the present invention an output signal of an exhaust gas sensor situated downstream from the three-way catalytic converter and which is correlated with a NOx concentration of the exhaust gas is used to set the air-fuel ratio in the first operating range. The invention is based on the finding that a NOx conversion brought about by the three-way catalytic converter is a sensitive function of the air-fuel ratio, in particular in a comparatively narrow range around the stoichiometric air-fuel ratio of \( \lambda = 1.0 \). Due to the output signal, used according to the invention, of an exhaust gas sensor which is situated in the exhaust emission control system downstream from the three-way catalytic converter and which provides an output signal that is correlated with a NOx concentration of the exhaust gas, information may be obtained concerning the air-fuel ratio, and the air-fuel ratio may be set.

[0005] In this regard, the \( \lambda \) value characterizing the air-fuel ratio is understood to mean, as is customary, a ratio of the quantity of oxygen actually present in the combustion air-fuel mixture to the minimum quantity of oxygen theoretically required for complete combustion of the fuel. A lean air-fuel mixture having excess air therefore has a \( \lambda \) value of greater than one. On the other hand, a rich air-fuel mixture having excess fuel has a \( \lambda \) value of less than one. In the absence of oxygen sources or sinks in the exhaust gas system the \( \lambda \) value in the exhaust gas (exhaust gas \( \lambda \)) corresponds to the lambda value of the air-fuel mixture (combustion \( \lambda \)) with which the engine is operated. For simplicity, therefore, reference is made below only to a \( \lambda \) value, or \( \lambda \) for short, when differentiation is not necessary.

[0006] The three-way catalytic converter is a catalytic converter that is able to remove nitrogen oxides (NOx) as well as reducing exhaust gas components such as carbon monoxide (CO) and hydrocarbons (HC) from the exhaust gas in a narrow range around \( \lambda = 1.0 \). Catalytic converter formulations with or without oxygen storage capacity for performing this function are known to those skilled in the art, in particular from applications concerning exhaust emission control of gasoline engines, so that no particular discussion of such is provided herein. The three-way catalytic converter may also be a classical (diesel) oxidation catalytic converter containing catalyst material having the mentioned three-way properties. “NOx” is collectively understood to mean at least the nitrogen oxides NO and NO₂.

[0007] The SCR catalytic converter is a catalytic converter that is able to selectively and continuously reduce NOx under oxidizing conditions, i.e., at \( \lambda > 1.0 \), using ammonia (NH₃). A particle filter is preferably situated between the three-way catalytic converter and the SCR catalytic converter.

[0008] The exhaust gas sensor is preferably a NOx sensor. This, however, does not exclude the possibility that, besides the output signal correlated with the NOx concentration of the exhaust gas, this sensor may also provide one or more output signals that are correlated with the concentration of another exhaust gas component such as oxygen, or with an exhaust gas state parameter such as the exhaust gas temperature.

[0009] A transition from operation at \( \lambda = 1.0 \) to normal operation typical of a diesel engine with excess air is provided when the SCR catalytic converter exceeds a predefined minimum temperature. This minimum temperature is preferably a catalytic converter temperature that is typical for a predefined NOx conversion, and which is correlated with the so-called light-off temperature or corresponds to same. The catalytic converter temperature is measured directly, or is computed based on an exhaust gas temperature determined by measurement upstream and/or downstream from the catalytic converter, or equated with same.

[0010] Using the method according to the invention with operation at \( \lambda = 1.0 \) during a warm-up phase of the exhaust emission control system, allows a large reduction in NOx even in this critical operating phase, in which the SCR catalytic converter does not yet exhibit, or at least does not exhibit satisfactory, NOx conversion. The reduction in NOx is carried out by the three-way catalytic converter. This is particularly advantageous for reducing the NOx emitted following a cold start.

[0011] In order to set the air-fuel ratio in the first operating range, in one embodiment of the invention an actual NOx conversion by the three-way catalytic converter is determined from the output signal of the exhaust gas sensor that is correlated with the NOx concentration, and a quantity of air and/or fuel supplied to the engine is varied until the actual NOx conversion at least approximately reaches a predefined set-point NOx conversion. The actual NOx conversion is determined by offsetting an uncontrolled NOx emission of the engine by the NOx concentration in the exhaust gas downstream from the three-way catalytic converter, which is ascertained by means of the exhaust gas sensor. Stored characteristic curves reflecting an uncontrolled NOx emission of the engine for the particular operating conditions are preferably utilized. However, the uncontrolled NOx emission may also be measured using a suitable sensor upstream from the three-way catalytic converter. Due to the \( \lambda \) dependency of the NOx conversion by the three-way catalytic converter, it is likewise possible to set a certain air-fuel ratio via parameters regarding the air and/or fuel supply that influence the NOx conversion.
by the three-way catalytic converter in a targeted manner; conversely, it is possible to set a certain NOx conversion by targeted influencing of the air-fuel ratio.

[0012] In another embodiment of the invention, a target value for the air-fuel ratio within a predefined target range is set in the first operating range. The target value is preferably in a narrow range around $\lambda \approx 1.0$ or a range adjacent thereto. A range of approximately $0.95 \leq \lambda < 1.05$ is preferred. Target ranges of $0.97 \leq \lambda < 1.0$ and $0.98 \leq \lambda < 1.05$ are particularly preferred.

In another embodiment a target value for the air-fuel ratio that oscillates within the target range is set. The oscillation frequency is preferably approximately 5 Hz to approximately 1 Hz. This ensures a good conversion characteristic of the three-way catalytic converter for CO and HC as well as for NOx.

[0013] In another embodiment of the invention, a pilot control value for the air-fuel ratio is set by pilot control by delivering a quantity of injected fuel necessary for a requested engine load, and delivering an at least approximate quantity of air necessary for combustion of same, and for setting the target value for the air-fuel ratio, the pilot control value is reduced by at least one delayed fuel post-injection which leaves the engine load at least essentially uninfluenced. Accurate and jerk-free setting of the intended air-fuel ratio is thus made possible. The quantity of air provided for the $\lambda$ pilot control value is preferably set by adjusting a throttle valve situated in the intake line of the engine, in conjunction with charge pressure regulation and setting of an amount of inert gas or recirculated exhaust gas to predefined pilot control values. The injected fuel quantity necessary for setting the engine load may be provided by one or more pre-injections made before top dead center, by a main injection made approximately at top dead center, and optionally by one or more post-injections that are, in particular, torque-effective. At least one post-injection is preferably added to the main injection. The pilot control value for the air-fuel ratio is preferably in the lean range. A pilot control value of $1.05 < \lambda < 1.20$, in particular $1.10 < \lambda < 1.15$, is particularly preferred. Thus, comparatively small changes set in an uncomplicated and torque-neutral manner are sufficient to achieve the target value of the air-fuel ratio. Based on the quantity of intake air, which is preferably known by measurement using an air mass meter and the known injection quantity of the torque-effective fuel injections, the additional quantity of post-injected fuel necessary for achieving the $\lambda$ target value may be calculated.

[0014] The at least one delayed post-injection used for setting the exact $\lambda$ target value is not torque-effective, or in any event is slightly torque-effective. This preferably occurs at crank angles of greater than 80° after top dead center, with the quantity of air and inert gases supplied to the engine preferably remaining unchanged.

[0015] In another embodiment of the invention, the target range for the air-fuel ratio is specified by associated setpoint NOx conversion values of the three-way catalytic converter, wherein for the association of air-fuel ratio values with setpoint NOx conversion values, a stored NOx conversion characteristic curve is utilized which reflects a dependency of the NOx conversion on the air-fuel ratio for the three-way catalytic converter. This characteristic curve is preferably determined in advance and stored in a control unit for controlling the engine operation and/or the operation of the exhaust emission control system. It is preferred that NOx conversion characteristic curves for various conditions be kept on hand so that the instantaneous conversion characteristic of the three-way catalytic converter may always be regarded as known. It is advantageous to estimate aging that occurs over time, and to adapt the NOx conversion characteristic curve, as necessary, to an age-related change in the NOx conversion characteristic. A characteristic map providing the instantaneous uncontrolled NOx emissions of the engine is likewise available in the control unit. The instantaneous actual NOx conversion by the three-way catalytic converter, and thus the instantaneous air-fuel ratio based on the NOx conversion characteristic curve of the three-way catalytic converter, may be determined based on the uncontrolled NOx emissions of the engine which are thus known, and the NOx concentration of the exhaust gas downstream from the three-way catalytic converter that is detected by the exhaust gas sensor by measurement. By appropriately changing or setting the quantity of air and/or fuel supplied to the engine, an intended air-fuel ratio is thus settable by approximating the actual NOx conversion to the corresponding setpoint NOx conversion.

[0016] It has proven to be particularly advantageous when, in another embodiment of the invention, the target range for the air-fuel ratio is adapted from time to time in the second operating range, an instantaneous actual NOx conversion by the three-way catalytic converter is determined, and in addition a correction value for an instantaneously set target value of the air-fuel ratio is determined in such a way that the target value of the air-fuel ratio that is corrected with the correction value corresponds to an air-fuel ratio to be associated with the actual NOx conversion, using the NOx conversion characteristic curve. Thus, based on the determined NOx conversion and the stored NOx conversion characteristic curve, a check is made as to whether a lambda value to be set in fact also corresponds to the $\lambda$ value to be expected according to the characteristic curve. Deviations are compensated for by a $\lambda$ offset correction. The correction values are preferably written into a characteristic map which is to be used for all relevant operating conditions of the first operating range for the $\lambda$ setting. An effective compensation for drift and/or aging effects is made possible by the adaptation carried out according to the invention. Setting an air-fuel ratio of approximately 1.0 in conjunction with a subsequent engine start or warm-up is thus made possible in an improved and more accurate manner. It is particularly advantageous when the adaptation is made immediately before or at least a short time before thermal regeneration of a particle filter is performed. For such an adaptation a decreased air-fuel ratio as well as an increased exhaust gas temperature are to be set anyway, so that reliable operation of the exhaust gas sensor is ensured while practically no further increase in fuel consumption results.

[0017] In another embodiment of the invention, the diesel engine is operated in the first operating range with excess air in a combustion process within a first temperature range for the three-way catalytic converter. This allows a particularly quick warm-up of the three-way catalytic converter. In this combustion process, fuel injection conditions that differ from normal operation are set, with which higher exhaust gas temperatures compared to normal operation may be generated. An exhaust gas temperature detected by measurement upstream or downstream from the three-way catalytic converter or a temperature determined in the catalyst bed itself is preferably regarded as representative of the temperature of the three-way catalytic converter.

[0018] The heating up of the exhaust emission control system may be further accelerated when, in another embodiment of the invention, in the first operating range an electric heating
element connected upstream from the three-way catalytic converter is energized within a second temperature range for the three-way catalytic converter. A preferred suitable heating element is a so-called E-catalytic converter, which as a disk-shaped, optionally catalytically coated, electrically heatable metal support element is connected directly upstream from the three-way catalytic converter. In another embodiment of the invention, it is particularly preferred to energize an electric heating element before the engine is started. Low-emission engine operation may thus be achieved particularly quickly, and pollutant emissions during warm-up may be kept particularly low. It is advantageous if, during the starting process itself, the heating is temporarily deactivated when electrical power is required by a starter for turning over the engine.

[0019] Further advantages, features, and particulars of the invention result from the following description of preferred exemplary embodiments, and with reference to the drawings. The features and feature combinations mentioned above in the description, as well as the features and feature combinations mentioned below in the description of the figures and/or shown in the figures alone, are usable not only in the particular stated combination, but also in other combinations or alone without departing from the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0020] The figures show the following:

[0021] FIG. 1 shows a schematic diagram of a motor vehicle diesel engine having an advantageous design of an exhaust emission control system connected thereto, in which the method according to the invention may be used.

[0022] FIG. 2 shows a diagram with a schematic illustration of operating ranges in which different operating conditions are provided, and

[0023] FIG. 3 shows a diagram with an example of a NOx conversion curve of the three-way catalytic converter.

DETAILED DESCRIPTION

[0024] FIG. 1 shows a schematic diagram of one advantageous embodiment of a motor vehicle diesel engine 1 having a connected exhaust emission control system in which the method explained in greater detail below may be used. In the present case, the diesel engine 1 has two-stage supercharging and two-stage exhaust gas recirculation, and includes an engine block 2 having working cylinders 3 with combustion chambers (not further identified), the working cylinders 3 and their respective combustion chambers can be supplied with fuel by means of a high-pressure pump 4. The working cylinders 3 and their respective combustion chambers may be supplied with combustion air via an air supply system 5, and exhaust gas may be discharged from the working cylinders 3 via an exhaust tract 6. An air filter 7, a first compressor 10 of a first exhaust gas turbocharger designed as a high-pressure exhaust gas turbocharger 11, a second compressor 8 of a second exhaust gas turbocharger designed as a low-pressure exhaust gas turbocharger 9, a charge air cooler 12, and a throttle valve 13 are situated in the air supply system 5.

[0025] Starting from the engine block 2 in the flow direction of the exhaust gas, a first turbine 14 associated with the high-pressure exhaust gas turbocharger 11, a second turbine 15 associated with the low-pressure exhaust gas turbocharger 9, and an exhaust emission control system 16 are situated in the exhaust tract 6. In the present case, the exhaust emission control system 16 has a particle filter 35 for filtering particles from the exhaust gas, and a three-way catalytic converter 34 connected upstream. In addition, an electric heating element, not illustrated, is provided directly upstream from the three-way catalytic converter 34. The three-way catalytic converter 34 is preferably designed as a so-called diesel oxidation catalytic converter having a three-way catalytic converter function, in particular with a metal foil support element. The electric heating element is also preferably designed as a coated metal foil support element (so-called E-catalytic converter). The particle filter 35 may have a sintered metal design, or may be a filter unit having a honeycomb design with flow through the walls. A catalytic coating, for example containing a material acting as an oxidation catalyst and/or containing an SCR catalyst material, is preferably provided for the particle filter 35.

[0026] In the present case, an SCR catalytic converter 36 is situated in the exhaust tract 6, downstream from the particle filter 35. The SCR catalytic converter 36 is capable of reducing nitrogen oxides (NOx), using ammonia in particular as a selective reducing agent. For enriching the exhaust gas with ammonia, upstream from the SCR catalytic converter 36 a dosing device 38 is provided that is able to inject ammonia or a reducing agent, for example a urea-water solution, which is capable of splitting ammonia, into the exhaust tract 6. For improving uniform distribution, a downstream mixer (not separately illustrated) may be situated in the exhaust tract 6. In the case of a particle filter 35 coated with an SCR catalyst, the dosing device may also be provided upstream from the three-way catalytic converter 34 or between the three-way catalytic converter 34 and the particle filter 35, or an additional NH3 dosing point may be provided at that location.

[0027] A compressor bypass 18 in which a compressor bypass valve 19 is situated and which bypasses the high-pressure exhaust gas turbocharger 11 branches off downstream from the second compressor 8, so that by means of the second compressor 8, compressed fresh air or a fresh air-exhaust gas mixture may pass through the first compressor 10 to a greater or lesser extent, depending on an operating state of the engine 1 and a resulting position of the compressor bypass valve 19. In this manner, a charge pressure of the engine 1 is controllable, i.e., at low speeds of the engine 1 in which the high-pressure exhaust gas turbocharger 11 is not yet operable due to exhaust gas pressure which is too low, the compressor 10 may be bypassed via the compressor bypass 18.

[0028] Likewise situated in the exhaust tract 6 are bypasses 20, 21, which bypass a turbine 14, 15, respectively, namely, a first turbine bypass 20 in which a first turbine bypass valve 22 is situated, and a second turbine bypass 21 in which a second turbine bypass valve 23 is situated. At low speeds of the engine 1 and thus a low exhaust gas pressure, the high-pressure exhaust gas turbocharger 11 is not yet operable, and therefore in this operating state the first turbine bypass valve 22 is controllable in such a way that an exhaust gas mass flow may be led past the first turbine 14 via the first turbine bypass 20, and thus is completely usable for driving the second turbine 15 of the low-pressure exhaust gas turbocharger 9.

[0029] At very high speeds of the engine 1, the exhaust gas pressure acting on the turbines 14, 15 of the exhaust gas turbochargers 11, 9, respectively, is high, thus achieving these high speeds. This results in high compressor power of the compressors 8, 10 of the exhaust gas turbochargers 9, 11,
respectively, and thus a high charge pressure of the fresh air-exhaust gas mixture. However, this charge pressure must not exceed a predefined value, so that one or both turbine bypasses 20, 21 are usable as a so-called wastegate when this predefined value is reached. The turbine bypass valves 22, 23 are controllable in such a way that, for example, they partially open so that a portion of the exhaust gas mass flow may be led past the turbines 14, 15, and therefore the exhaust gas pressure acting on the turbines 14, 15 and drives same may be reduced. This results in a lesser degree of compression of the gas compressed by the compressors 8, 10 of the exhaust gas turbocharger 9, 11, respectively, i.e., results in a lower charge pressure.

By means of this configuration of the low-pressure exhaust gas turbocharger 9 and the high-pressure exhaust gas turbocharger 11, power of the engine 1 in different speed ranges may be optimized, and an optimal charge pressure may be provided in each case. In particular, so-called turbo lag, i.e., an absent or low charge pressure, and consequently low power of this type of engine 1 in low speed ranges, is thus preventable, or this problem may be at least considerably reduced, and, for example, driving behavior and fuel consumption of a vehicle driven by this engine 1 may thus be optimized.

Downstream from the particle filter 35 and upstream from the dosing device 38, i.e., on a low-pressure side of the exhaust tract 6, a low-pressure exhaust gas recirculation (EGR) line 24 branches off from the exhaust tract 6, and upstream from the second compressor 8 of the low-pressure exhaust gas turbocharger 9 and downstream from the air filter 7 in turn opens into the air supply system 5. The quantity or proportion of exhaust gas recirculated via the low-pressure exhaust gas recirculation line 24 may be influenced by means of an exhaust gas damming flap 17 situated in the exhaust tract 6. Although in the present case the exhaust gas damming flap 17 is illustrated situated downstream from the branch point of the low-pressure exhaust gas recirculation line 24, it may also be situated downstream from the SCR catalytic converter 36.

A low-pressure EGR cooler 25 and a low-pressure EGR valve 26 are situated in the low-pressure EGR line 24, downstream from the branch from the exhaust tract 6 viewed in the flow direction of a low-pressure EGR mass flow. Optionally, the cooling of the low-pressure EGR mass flow may be achieved via the pipe lengths or pipe configurations used, with omission of the low-pressure EGR cooler 25. The cooling of the low-pressure EGR mass flow ensures that no impermissibly high temperatures arise at the compressors 8, 10 in exhaust gas recirculation mode.

A second SCR catalytic converter, not illustrated, in the low-pressure EGR line 24 may be provided upstream from the low-pressure EGR cooler 25. This second SCR catalytic converter allows a reduction in the nitrogen oxides and/or ammonia or oxygen that may be present in the recirculated exhaust gas. In turn, deposits and corrosion are thus avoided or decreased, and an improved fuel combustion process in the combustion chambers of the engine 1 is made possible. The second SCR catalytic converter may also take over a filter function, so that at least comparatively coarse particles are removed from the exhaust gas recirculated via the low-pressure path. In addition, one or more further exhaust aftertreatment components effective in cleaning, for example an additional oxidation catalytic converter, an SCR catalytic converter, and/or a nitrogen oxides storage catalytic converter (not separately illustrated) may be situated in the exhaust tract 6, upstream and/or downstream from the three-way catalytic converter 34 or the particle filter 35. It is particularly preferred for an exhaust emission control component having oxidation catalyst activity to be situated downstream from the SCR catalytic converter 36, by means of which ammonia slip of the SCR catalytic converter 36 may be removed from the exhaust gas.

Upstream from the turbine 14 of the high-pressure exhaust gas turbocharger 11, i.e., on a high-pressure side of the exhaust tract 6, a high-pressure EGR line 27 branches off from an exhaust manifold 33 of the exhaust tract 6 and opens into the air supply system 5 downstream from the throttle valve 13. A high-pressure EGR mass flow may be led into the air supply system 5 via a high-pressure EGR valve 28 by means of this high-pressure EGR line 27. In the illustrated embodiment, a high-pressure EGR cooler 29, which optionally may be structurally and/or functionally combined with the low-pressure EGR cooler 25, is situated in the high-pressure EGR line 27. However, cooling of the high-pressure EGR mass flow may optionally be carried out, for example, over a pipe length of the high-pressure EGR line 27. Bypass lines, in particular having adjusting means (not separately illustrated) for variably setting the throughput, may be provided for the low-pressure EGR cooler 25 and/or the high-pressure EGR cooler 29.

The illustrated diesel engine 1 thus has an exhaust gas recirculation system in which exhaust gas upstream from the turbine 14 of the high-pressure exhaust gas turbocharger 11 is movable from the exhaust tract 6 via a corresponding high-pressure path, and downstream from the exhaust emission control unit 16 is movable from the exhaust tract 6 via a corresponding low-pressure path, and, optionally after cooling, can be supplied upstream from the compressor 8 of the low-pressure exhaust gas turbocharger 9 and downstream from the throttle valve 13 of the air supply system 5, and thus can be supplied to the combustion chambers 3. The engine 1 is selectively operable without exhaust gas recirculation, with high-pressure exhaust gas recirculation or low-pressure exhaust gas recirculation, or simultaneously with high-pressure exhaust gas recirculation and low-pressure exhaust gas recirculation, in each case with variable quantities of recirculated exhaust gas. A combustion gas having an exhaust gas recirculation rate, having a variable low-pressure component and a variable high-pressure component which are changeable within wide limits, is thus can be supplied to the combustion chambers 3. Setting of an exhaust gas recirculation quantity, i.e., of the recirculated exhaust gas mass flow and thus of the EGR rate, is carried out by means of the exhaust gas damming flap 17 and/or the low-pressure EGR valve 26 and by means of the high-pressure EGR valve 28 as adjusting means, so that the low-pressure component as well as the high-pressure component of the overall recirculated exhaust gas is like wise settable within wide limits. This results in cleaner exhaust gas recirculation mass flows overall and better cooling of the exhaust gas recirculation mass flows, avoids scoting of the exhaust gas recirculation coolers 25, 29, and allows good mixing of the exhaust gas recirculation mass flows with fresh air in the air supply system 5. High exhaust gas recirculation rates, and a homogeneous or at least partially homogeneous operation of the internal combustion engine 1, are possible.

In the present case, the exhaust gas damming flap 17 and the low-pressure EGR valve 26 are actuators of an exhaust gas recirculation control system designed as pilot
control regulation. The low-pressure EGR valve 26 and the exhaust gas damming flap 17 are preferably continuously adjustable. The low-pressure component of the entire exhaust gas recirculation mass flow is settable and likewise can be influenced with the aid of the exhaust gas damming flap 17 and the low-pressure EGR valve 26 upstream from the compressor 8. As long as a sufficient pressure drop is present for conveying the low-pressure exhaust gas recirculation mass flow, the latter is initially settable solely via the low-pressure EGR valve 26. If this is no longer the case, in addition the exhaust gas damming flap 17 is slightly adjustable in order to increase the pressure drop over the low-pressure EGR valve 26. This ensures very good intermixing of the low-pressure exhaust gas recirculation mass flow with the fresh air. Another advantage, among others, is that the exhaust gas recirculated via the low-pressure path is clean and practically free of pulsations. In addition, increased compressor power is available because a comparatively high exhaust gas mass flow may be led through the turbines 14, 15 for a high low-pressure component of recirculated exhaust gas. Since the recirculated exhaust gas may be led through the efficient charge air cooler 12 after leaving the compressors 8, 10, the temperature of the combustion gas that includes fresh air and exhaust gas may also be kept relatively cool. The internal combustion engine 1 is operable with the high-pressure exhaust gas recirculation as well as with the low-pressure exhaust gas recirculation, or with both, as needed.

Sooting of the charge air cooler 12 is avoidable by means of a preferably provided charge air cooler bypass 30, bypassing the charge air cooler 12, in the air supply system 5. There is a risk of so-called sooting, for example, when a gas mixture, containing water vapor and optionally particles, in the charge air cooler 12 is cooled below the dew point and condensate is formed.

Preferably the entire fresh air-exhaust gas mixture or also only a portion thereof may be led past the charge air cooler 12 via the charge air cooler bypass 30 that branches off upstream from the charge air cooler 12, so that the fresh air-exhaust gas mixture is not coolable by the charge air cooler 12, and therefore the temperature does not fall below the dew point. To ensure that the fresh air-exhaust gas mixture is still effectively coolable by the charge air cooler 12 when necessary, i.e., at high temperatures of the fresh air-exhaust gas mixture, a temperature sensor 31 is situated downstream from the compressors 8, 10 and upstream from the charge air cooler 12 in the air supply system 5, so that when a predefined temperature is reached, a charge air cooler bypass valve 32 is activated, whereupon this charge air cooler bypass valve 32 completely opens or completely closes, for example, or in another embodiment, partially opens.

For optimal operation of the engine 1 and the exhaust aftertreatment system 16, additional sensors, not illustrated in greater detail for the sake of clarity, are preferably provided in the exhaust tract 6 and in the air supply system 5. Temperature sensors and/or pressure sensors may be situated on the output side of the exhaust manifold 33, in the turbine bypasses 20, 21 on the input and/or output side or within the combination of the three-way catalytic converter 34 and particle filter 35 exhaust emission control module, which is preferably designed as a compact unit, on the input and/or output side of the SCR catalytic converter 36, on the input and/or output side of the air filter 7, on the input and output side of the compressors 8, 10, in the exhaust gas recirculation lines 24, 27, and optionally at other locations in order to detect the temperature and pressure conditions. An air mass flow sensor is also preferably provided downstream from the air filter 7 in order to detect the fresh air mass flow. In addition, exhaust gas sensors are preferably provided in the exhaust tract 6, for example a lambda sensor in the exhaust manifold 33, situated upstream and/or downstream from the three-way catalytic converter 34 and the particle filter 35. In particular, according to the invention an exhaust gas sensor preferably designed as a NOx sensor is provided between the particle filter and the dosing device 38 or the branch from the low-pressure EGR line 24. The NOx sensor may emit an output signal that is correlated with a NOx concentration of the exhaust gas, and optionally may emit further output signals, in particular an output signal that is correlated with the exhaust gas λ. In addition, a NOx sensor, likewise not separately illustrated, may be provided on the output side of the SCR catalytic converter 36.

[0040] The signals of the sensors that are present can be processed by a control unit, not illustrated, which, based on the signals and stored characteristic curves and characteristic maps, is able to determine operating states of the engine 1 in general, in particular in the exhaust tract 6 and in the air supply system 5, and to set same via control and/or regulation by controlling actuators. In particular, exhaust gas recirculation mass flows in the low- and high-pressure path as well as a load state of the engine 1 with regard to torque or average pressure as well as speed may be determined or set. In addition, fuel injection parameters such as the number of fuel injections per working cycle and the injection pressure, duration, and time thereof may be set.

[0041] The operating method according to the invention is described in greater detail below with reference to operating ranges designated in the diagram in FIG. 2. The operating ranges denoted by reference characters A through G are defined by values for a temperature T and for an engine load M relative to a nominal load, expressed as an effective average pressure p_{mean}, for example. The temperature T is a temperature in the exhaust tract 6 that occurs directly downstream from the three-way catalytic converter 34, and which is preferably detected using a temperature sensor and which is regarded as a measure for the temperature of the three-way catalytic converter 34. In the following discussion, without limiting universality, it is assumed by way of example that the operating ranges designated by reference characters A through G are occupied in alphabetical order, starting from an engine cold start at temperatures of the engine 1 and of the exhaust emission control system 16 of 30°C or less. It is further assumed that, apart from operating range G, a temperature of the SCR catalytic converter 36 or an exhaust gas temperature which is measurable directly upstream or downstream from the SCR catalytic converter 36 has not yet exceeded 200°C.

[0042] After an engine cold start, the exhaust emission control system 16 is still cold, and does not heat up until heat is absorbed as exhaust gas having a more or less elevated temperature flows through. In operating range A, characterized by a temperature T<150°C and an engine load M covering the entire load range, the electric heating element, situated directly on the input side of the three-way catalytic converter 34, is energized for rapid heating of the exhaust emission control system 16 and in particular of the three-way catalytic converter 34. The energization may be started at the beginning of independent sustained operation of the engine.
However, it is preferred if the energization is begun before the engine is started. Recognition of a door lock activation or driver's seat occupancy or seat belt locking may be provided as a trigger for this purpose. In addition, after the engine is started it is operated with excess air, as is typical for a diesel engine, but with a specific combustion process that results in a higher exhaust gas temperature compared to normal diesel engine operation. In the combustion process, the main fuel injection is retarded to approximately 3° crank angle after top dead center to 7° crank angle after top dead center (start of control), and the main injection quantity is decreased in favor of the quantity of the added post-injection. In addition, the injection pressure may lowered. Furthermore, one or two pre-injections before top dead center is/are provided. Characteristically, a post-injection that does not completely combust is omitted in order to avoid increased HC/CO emissions, which would result due to a temperature-related lack of activity of the three-way catalytic converter 34.

However, such a post-injection, preferably at crank angles of greater than 80° after top dead center for the start of control, is carried out in operating range B in addition to the measures provided in operating range A. As illustrated in Fig. 2, operating range B is characterized by a temperature in the range of 150° C.<T<250° C. and an engine load M covering the entire load range. A more or less high level of HC conversion by the three-way catalytic converter 34 is already made possible in this operating range. Due to the heat of reaction thus released, the three-way catalytic converter heats up quickly, and the activity therefore likewise quickly increases.

Upon further heating of the three-way catalytic converter 34 to a temperature range of 250° C.<T<350° C., operating ranges C and D are reached, depending on the engine load M. Operating range C is additionally characterized by an engine load M of less than 20%, and operating range D is characterized by an engine load M of greater than 20%, of the nominal load. The energization of the electric heating element preferably remains active in operating ranges C and D. Due to the continued heating of the three-way catalytic converter 34, in operating ranges C and D it is operational with regard to its three-way function, and the engine 1 is switched to operation having a combustion λ of approximately 1.0. A target value for the air-fuel ratio λ which oscillates in a target range between a lower and an upper limit value is set. In operating range C a combustion λ of 0.97, and in operating range D a combustion λ of 0.98, is provided as the lower limit value. Values of 1.0 and 1.05 are set in operating range C and D, respectively, as the upper limit value. CH₄ and N₂O emissions are advantageously reduced in operating range C due to the slightly lower average value of the combustion λ in this operating range.

The procedure provided according to the invention for setting the combustion λ of approximately 1.0 is explained in greater detail below. In this regard, reference is made to a NOx conversion curve of the three-way catalytic converter 34 schematically depicted in Fig. 3. This curve represents, strictly by way of example, a stored λ dependency of the NOx conversion by the three-way catalytic converter 34 which is relevant for the operating range. A λ target range Δλ of 0.98<λ<1.05 is plotted as an example. In the present case, this corresponds to a target range between 49% and 94% for the NOx conversion.

For setting the λ target value in the λ target range Δλ, initially a pilot control value is set for the air-fuel ratio in the range between λ=1.10 and λ=1.15. For this purpose, the air feed quantity and the exhaust gas recirculation quantity are set to pilot control values as a function of the operating point by actuating the throttle valve 13, adjusting means for the exhaust gas turbochargers 9, 11, and the EGR valves 26, 28, and the quantity of fuel required for the λ pilot control value is set via the sum of the pre-injection, the main injection, and the added post-injection. Typically, the throttle valve is closed to values between 70% and 95%, a charge pressure valve is closed to values between 5% and 45%, and a waste gate is closed to values between 25% and 45%. The high-pressure EGR valve 28 is preferably completely closed, and the exhaust gas recirculation quantity is set by actuating the low-pressure exhaust gas recirculation valve 26 and the exhaust gas damming flaps 17. By offsetting a computed pilot control quantity of a delayed post-injection that is not torque-effective, at a crank angle of 80° after top dead center, enrichment occurs for achieving the λ target value. The exact value thereof is determined by computing the actual NOx conversion by the three-way catalytic converter 34 and utilizing the NOx conversion curve. To compute the actual NOx conversion, the uncontrolled NOx emission of the engine stored in the characteristic map is offset by the NOx concentration of the exhaust gas that is determined by measurement by the exhaust gas sensor downstream from the three-way catalytic converter 34. By incrementally increasing or decreasing the quantity of fuel injected in a delayed manner, the measured NOx conversion is increased or decreased, respectively, in such a way that the measured NOx conversion assumes a setpoint value within the target range, and therefore the λ target value is within the λ target range. An oscillating sweep of the λ target range takes place at a frequency between 1 and 5 Hz.

An improvement in the accuracy of the setting of the post-injection quantity is made possible by an adaptation occurring from time to time, preferably just before a required thermal regeneration of the particle filter. Starting from an operation of the engine 1 with excess air similarly as for the above-described procedure, a λ value is set that should correspond to a predefined λ target value in the λ target range Δλ. The associated actual λ value of the air-fuel ratio is ascertained by determining the actual NOx conversion and utilizing the NOx conversion curve. If deviations from the λ target value are identified, a correction value is determined in such a way that adding the correction value to the λ target value results in the actual λ value. This adaptation improves the accuracy of a setting of the air-fuel ratio of approximately λ=1.0 which is carried out at a later point in time.

The settings of the other provided operating ranges are explained below, once again with reference to the diagram illustrated in FIG. 2. Upon further heating of the three-way catalytic converter 34, operating range D is reached, with a temperature of 350° C.<T<450° C. measured on the output side and an engine load M<20%. With the exception of the deactivated heating element, the settings made here correspond to those of operating range C. Similarly as for operating range C, formation of nitrous oxide and/or methane at the three-way catalytic converter 34 is largely avoidable due to the slightly richer λ balancing compared to operating range D. In subsequent operating range F at higher temperatures up to 1565° C., and at higher engine loads M, once again apart from the deactivated heating element the settings of operating range D are provided. Above a temperature of 1565° C., in operating range C the engine 1 is operated normally, i.e., with
excess air that is typical for diesel engine operation, since it is assumed here that the SCR catalytic converter 34 has exceeded a temperature of at least 180°C and is operational.

[0049] It is understood that the above-described operating ranges A through G do not necessarily have to be occupied in their alphabetical order. Depending on the driving operation, and therefore as a function of the exhaust gas temperature and the exhaust gas mass flow, operating ranges A through G may instead be achieved in alternation and distributed over time.

[0050] Within the scope of the described procedure, an estimate an aging-related loss in conversion by the three-way catalytic converter 34 occurring over time can be employed. The temperature limits which delineate operating ranges A through G from one another are raised in correlation with the determined aging. This is provided in particular for the temperature limits between operating ranges A and B, and B and C and B and D.

[0051] The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.

11. An operating method for a motor vehicle diesel engine having an exhaust emission control system comprising a three-way catalytic converter and an SCR catalytic converter situated one behind the other in the flow direction of the exhaust gas, the method comprising:

operating, at least temporarily, the diesel engine with an air-fuel ratio target value of approximately λ=1.0 within an air-fuel ratio target range in a first operating range, wherein in the first operating range the SCR catalytic converter has a temperature below a predetermined minimum temperature; and

operating the diesel engine with excess air in a second operating range, wherein in the second operating range the SCR catalytic converter has a temperature exceeding the predetermined minimum temperature.

wherein in the first operating range a NOx conversion by the three-way catalytic converter is determined by an exhaust gas sensor situated downstream from the three-way catalytic converter, and a quantity of air and/or fuel supplied to the engine is adjusted, utilizing a characteristic curve indicating the NOx conversion as a function of the air-fuel ratio in such a way that a setpoint NOx conversion associated with the air-fuel ratio target value is at least approximately reached.

12. The method according to claim 11, wherein the diesel engine is operated with the air-fuel ratio target value within approximately 0.95<λ<1.05 in the first operating range.

13. The method according to claim 12, wherein an oscillating air-fuel ratio target value is set within the air-fuel ratio target range.

14. The method according to claim 13, wherein the oscillating air-fuel ratio target value is set at an oscillation frequency of approximately 5 Hz to approximately 1 Hz.

15. The method according to claim 11, wherein a pilot control value for the air-fuel ratio is set by pilot control by delivering a quantity of injected fuel necessary for a requested engine load, and delivering an at least approximate quantity of air necessary for combustion of the injected fuel, and for setting the air-fuel ratio target value, the pilot control value is reduced by at least one delayed fuel post-injection that leaves the engine load at least essentially uninfluenced.

16. The method according to claim 15, wherein the set pilot control value is 1.05<λ<1.20.

17. The method according to claim 11, wherein in the first operating range the diesel engine is operated with excess air in a combustion process within a first temperature range for the three-way catalytic converter.

18. The method according to claim 11, wherein in the first operating range an electric heating element connected upstream from the three-way catalytic converter is energized within a second temperature range for the three-way catalytic converter.

19. The method according to claim 18, wherein the electric heating element is energized before the engine is started.

20. The method according to claim 11, wherein combustion air supplied to the diesel engine is selectively compressed (1) only by a compressor of a low-pressure exhaust gas turbocharger, or (2) is additionally compressed by a compressor of a high-pressure exhaust gas turbocharger.

21. The method according to claim 11, wherein exhaust gas is supplied to the SCR catalytic converter is filtered by a particle filter situated in the exhaust emission control system downstream from the three-way catalytic converter.

22. The method according to claim 21, wherein the particle filter has an SCR catalyst coating.

23. The method according to claim 21, wherein a urea-water solution is into the exhaust gas by a dosing device situated upstream from the SCR catalytic converter.

24. The method according to claim 23, wherein the dosing device is situated downstream from the particle filter and upstream from the SCR catalytic converter.

25. The method according to claim 24, wherein the combustion air of the diesel engine exhaust gas is added via a low-pressure exhaust gas recirculation line that branches off downstream from the particle filter and upstream from the dosing device, or via a high-pressure exhaust gas recirculation line branching off from an exhaust manifold.

26. The method according to claim 11, wherein for the minimum temperature at and above which the diesel engine is operated with excess air, a temperature is selected above which the SCR catalytic converter is operational.

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